PHYSIOLOGY.—*The electrogram of the turtle heart in situ and after isolation.*[1]
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The durability of the turtle heart makes it suitable for a variety of physiological studies. Even after isolation the heart exhibits rhythmic beating for long periods of time. This hardiness has prompted investigators to use the isolated turtle heart in a variety of studies including hypothermia (Adolph, 1951), contractility (Katzung and Farah, 1956), and bioelectricity (Churney et al., 1948).

Izquierdo (1930) reported that excision of the frog's heart has a profound affect on heart rate. The heart rate at first accelerates, then decreases and finally, after approximately 25 minutes, reaches a steady state which approaches the heart rate *in situ*. With this in mind, it was decided to observe the effect of isolation of the turtle heart on heart rate. When preliminary studies indicated that a sharp decline in rate immediately followed excision, it was decided to pursue the study further and quantitatively study the effect of excision on the components of the electrogram.

MATERIAL AND METHODS

The turtle *Pseudemys elegans* was used for this investigation. The specimens were purchased from Carolina Biological Supply Co. and divided in three groups. Group A, consisting of seven turtles, was maintained at 18°–22° C and served as a control. Group B, consisting of 12 turtles, was refrigerated at 3° C. for 1 month, while Group C (12 turtles) was exposed to short-term hypothermia (colon temperature 4° C. for 2 minutes). The Group C specimens were then rapidly rewarmed, and electrograms recorded, *in situ* and after isolation.

Electrograms (electrocardiograms recorded directly from the heart surface) were obtained as follows: The animals were pithed, the carapace and pericardium removed, and an exploring electrode placed on the apex of the ventricle. The electrodes were made of 26-gauge silver wire mounted in glass tubing. The electrode tip was covered with blood-soaked cotton so that good contact was affected with no damage to the musculature. The indifferent electrode was in contact with a seared portion of the pubis.

This set-up is similar to the precordial lead IVF used on human beings (Hein and Reavis, 1950). The hearts were then isolated and transferred to Petri dishes containing amphibian Ringer's solution (room temperature) after the aortic trunk and the pre- and postcaval veins were ligated. Amphibian Ringer's solution consists of NaCl 6.5 gm, KCl 0.140 gm, $CaCl_2$ 0.120 gm, $NaHCO_3$ 0.200 gm, and H_2O 1000 ml (pH 7.65). The exploring electrode was, once again, placed on the ventricle apex (which was not submerged during recording), while the indifferent electrode was 2–3 inches away immersed in Ringer's solution. Isolation and recording was completed within two minutes.

A Grass Instrument Co. model IIIB electroencephalograph was used for recording the electrograms. Electrograms were studied and interpreted after standard measurements of the records were obtained.

RESULTS

Heart rate.—The results are summarized in Table 1. In all three groups there was a decrease in the mean heart rate upon excision. In the control group, the heart rate of five of the seven specimens decreased markedly upon isolation; it remained constant in the other two preparations. The change was from 34 to 23 beats/minute. Group B had a mean heart rate of 37 (after rewarming) which fell to 30 beats/minute after isolation. Group C had a mean rate of 29 (after rewarming), which fell to 25 beats/minute after isolation. Of the 31 specimens

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studied, the heart rate decreased immediately after isolation in 23 cases; it remained constant in four cases and increased in four cases.

Electrogram in situ.—The electrogram shown in Fig. 1a is typical of those recorded from the three groups. The P wave was upright in 17 specimens, diphasic in 7, negative in 5, and undiscernible in 2 specimens (Table 2). The upright QRS complex was in 24 instances, N-shaped, and slurred on the upstroke. It was rounded in four cases and notched in three.

The T wave was diphasic in all specimens. Twelve specimens had a + − type T wave (4 Group A, 5 Group B, and 3 Group C). The 19 − + type T waves were distributed as follows: Group A, 3; Group B, 7; Group C, 9. In all other respects, the *in situ* electrograms of the three groups were similar.

Table 1.—Heart Rate and Dimensions of the Electrogram Components Recorded from Three Groups of Turtle Hearts, in Situ and after Isolation

Group A, control; Group B, long-term hypothermia; Group C, short-term hypothermia.

	Group A		Group B		Group C	
	In situ	Isolated	In situ	Isolated	In situ	Isolated
Duration P, sec	0.06	0.10	0.08	0.09	0.09	0.09
Duration P-R segment, sec	0.27	0.37	0.37	0.37	0.56	0.48
Amplitude R, millivolts	4.3	2.5	4.1	2.4	6.0	3.1
Duration R, sec	0.09	0.09	0.09	0.07	0.13	0.11
Duration Q-T interval, sec	1.28	1.72	1.31	1.51	1.51	1.76
Duration of T, sec	0.45	0.80	0.63	0.93	0.74	0.85
Heart rate, beats/minute	34	23	37	30	29	25

Table 2.—The Electrical Nature of the P and T Waves of the Electrogram of the Turtle Heart in Situ and after Isolation

Group A, control; Group B, long-term hypothermia; Group C, short-term hypothermia.

	Group A				Group B				Group C			
	P Wave		T Wave		P Wave		T Wave		P Wave		T Wave	
	In situ	Isolated	In situ	Isolated	In situ	Isolated	In situ	Isolated	In situ	Isolated	In situ	Isolated
Number +	2	1	0	0	8	1	0	1	7	0	0	1
Number −	2	3	0	0	2	10	0	1	1	9	0	0
Number −+	1	1	3	3	2	1	7	5	4	3	9	8
Number +−	0	2	4	4	0	0	5	5	0	0	3	3
Number indiscernible	2	0	0	0	0	0	0	0	0	0	0	0
Number changing sign upon isolation		3*		2		9		4		9		6

* This is only a minimum because 1 P wave was indiscernible because of flutter.

Electrogram after isolation of heart.—The major effect of isolation of the heart on the P wave was the change in direction of the wave, especially in Groups B and C. These results are summarized in Table 2. The effect of isolation of the heart on the R wave shape was evident in all groups especially B and C. *In situ*, 24 specimens showed a normal, slurred upstroke of the QRS complex. After isolation, such a configuration was evident in only 15 specimens (3 in Group A, 8 in Group B, and 4 in Group C). The main change was in the rounding or notching of the upstroke of the QRS complex (Fig. 1b).

Note (Table 1) that the heart rate decline after isolation is due to changes in duration of ecg components other than the R wave. The P wave and Q-T interval increased in duration, substantially. The amplitude of the R wave was diminished.

DISCUSSION

Kisch (1949) studied the electrogram of the univentricular heart (fish and bullfrog). He found that the electrogram recorded from the apex consisted of a high R and a small S component. In these studies (*in situ*) the S wave was almost always very deep (4 mv). Our studies on the electrogram of *Rana pipiens* show greater variability of the S wave than those recorded from the turtle. The T wave of the turtle electrogram was always diphasic. The electrograms recorded by Kisch (1949) were recorded using a modified form of Wilson's central terminal for an indifferent electrode. They show an upright T wave in the frog electrogram and a downward T wave in the fish electrogram. Hein and Reavis (1950) report a downward T wave for a V4 and D4 human electrogram. Burch and Winsor (1949) report that the human adults rarely, if ever, have a negative lead 4V; furthermore, the T wave is rarely notched or diphasic. The diphasic T wave

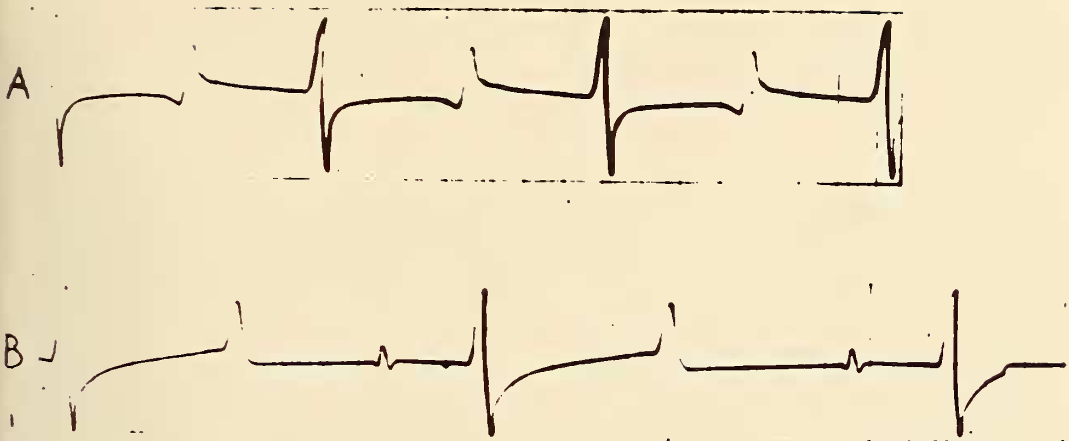

Fig. 1.—A, Typical electrogram with heart *in situ;* B, typical electrogram after isolation of the heart.

suggests that the repolarization pattern in the normal turtle is typical of systems with tissues of diverse repolarization rates (Churney, et al., 1948). This view is supported by the histological study of Robb (1953) which shows that the turtle heart contains a variety of muscular tissues.

Izquierdo (1930) maintains that the change in the heart rate of the isolated frog heart is due to the difference in composition of the ionic solution as compared with blood. These studies, while demonstrating a uniformity of response in three groups of turtles, does not offer information relative to this problem. What is of significance, however, is the fact that the decrease in heart rate accompanying isolation is attributable to components of the electrogram other than the QRS complex. If Izquierdo's view is correct, then it would be indicated that the ventricle conducting system is far less sensitive to changes in ionic composition than are the auricular conducting system and the factors responsible for repolarizarion—at least under the conditions of this experiment. The P wave was negative in 22 isolated hearts and negative in only 3 hearts *in situ* which suggests that after isolation, the direction of depolarization may be changed so that depolarization now proceeds from the epicardial surface to the endocardial surface instead of in the reverse direction. The R duration was not affected while the duration of the Q-T interval and T wave were greatly affected. The R wave amplitude, however, did decrease after isolation of the heart.

SUMMARY

A study of the heart rate and electrogram of the turtle heart *in situ* and after isolation, was made. Isolation of the heart resulted in a decrease in heart rate, change in direction of the P wave, diminution of the R amplitude, and increase in duration of the Q-T interval. The duration of the R wave was not affected. The T wave was almost always diphasic, *in situ* and after isolation. Little difference was noted when the electrograms of control animals were compared to the electrograms of turtles exposed to short-term and long-term hypothermia.

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